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A COMPARISON OF WIND SPEEDS RECORDED SIMULTANEOUSLY AT THREE METRES AND TEN METRES ABOVE GROUND

by

Angus Headley

ATMOSPHERIC ENVIRONMENT SERVICE

DOWNSVIEW, ONTARIO

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ABSTRACT

This study examines the relationship between the wind speeds recorded at 3 metres and those recorded at 10 metres. A mean variation of wind speed with height based on a simplified form of Hellman's formula is used to adjust the 3-metre wind speeds to provide an estimate of the 10-metre speeds. The effectiveness of this principle is also evaluated.

RESUMÉ

On examine dans cette étude le rapport entre la vitesse du vent mesurée à 3 m à celle mesurée à 10 m. On a aussi calculé la vitesse du vent à 10 m à partir de celle mesurée à 3 m en faisant usage d'une version simplifiée de la formulation de Hellman. On a comparé les valeurs calculées à 10 m aux valeurs mesurées et on a aussi évalué la validité de la méthode de Hellman.

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A COMPARISON OF WIND SPEEDS RECORDED SIMULTANEOUSLY AT THREE METRES AND TEN METRES ABOVE GROUND.

1. Introduction

Anemometers are normally exposed at the internationally agreed height of 10 metres. Throughout this paper, height is considered to be the vertical distance of an object above ground but elevation is the measurement above sea level. With the advent of the automated weather station, researchers are now taking wind measurements at remote locations where it was virtually impossible to do so before. This was mainly due to scarcity of adequate transportation and support staff. These measurements are not usually observed at the internationally agreed height but at any height that is convenient for the researcher or one that fits the requirements of the particular study. Many researchers are now using the 3-metre tripod but this height, and any other non-standard height, makes comparison of the resulting data with those from standard network stations very difficult.

During the summer of 1989, an anemometer was installed on a 10-metre light-weight aluminum pole at a remote high-arctic location where long-term wind measurements were already being made at the 3-metre level. Wind speed data were recorded simultaneously at the two levels for a period of two and one-half months (June 25 to August 19). In this study, the resulting two data sets are being used in an attempt to gain a better understanding of the comparability of the wind speeds at these two heights. Although wind speed will be the only variable that will be fully analyzed, wind directions will also be examined in an effort to understand any unusual or readily unexplainable data.

2. Site Location

The site is located at 79° 58'N and 84° 28'W on Fosheim Peninsula, Ellesmere Island. The elevation is approximately 115 metres but the terrain slopes gradually downwards to a lowland drained by Hot Weather Creek about half a kilometre to the east and some 30 metres below. East of the creek, the terrain is gently rolling for a distance of approximately 30 kilometres until it reaches the Sawtooth Range which has an elevation of 1200 metres. To the west of the site, the terrain is also rolling and the nearest topographical feature of any significance is Black Top Ridge, some 20 kilometres distant, with an elevation of 300 metres (see Figure 1). The 10-metre wind sensor was installed about 20 metres away from the 3-metre long-term autostation and the descriptions of the two sites are identical. The north-south orientation of Hot Weather Creek and its associated lowlands will have some influence of the winds observed at this site. Figure 2 shows the terrain sloping upwards to the instrument site from the lowlands drained by Hot Weather Creek.

Figure 1: Location of study area on Fosheim Peninsula, Ellesmere Island.

Figure 2: The terrain sloping upwards from the lowlands drained by Hot Weather Creek to the instrument site. (Courtesy Dr. Sylvia Edlund, TS/GSC)

3. Instrumentation

3.1. Datalogger and Program: Campbell Scientific CR10 microloggers were used to monitor and collect the data at both installations. A scan rate of 60 seconds was used and the wind directions and speeds were stored over the two-minute period prior to the hour. On the hour UTC (Universal Coordinated Time), a mean two-minute wind speed and a mean two-minute vector direction were stored for use in this analysis.

3.2. 3-metre Sensor: A Met-One 013A wind speed sensor is being used for the long-term sensitivity program at Hot Weather Creek. The anemometer consists of three aluminum cups mounted on a mounting hub. The cup assembly is mechanically linked to a magnet by a stainless steel shaft which turns on a precision-sealed ball bearing. The rotation of the magnet causes the reed switch contacts to open and close. The frequency of the closures is linear from the sensor's threshold speed of 1.8 km/h to 160 km/h. (Campbell Scientific, Inc., 1982).

3.3. 10-metre Sensor: The R.M. Young 05103 Wind Monitor was installed at 10 metres for the wind comparison study; this sensor has a lightweight helicoid-shape propeller moulded of polypropylene plastic. The propeller has four blades and its rotation produces an AC sine wave voltage signal with a frequency directly proportional to wind speed. A potentiometer is employed to measure wind direction and the threshold speed of the propeller is 2.2 km/h (R.M. Young Company, 1985).

Although it would have been preferable to use identical sensors for this type of study, the somewhat fragile light-weight 10-metre pole and the shortage of support limited the installation to a sensor which did not require the use of a cross arm mount.

The wind sensors were tested in the wind tunnel prior to installation and a linear regression technique was used to estimate the best fit line from the various observations taken against the known tunnel speeds. The two equations derived from this test will be used later in this study to estimate a true speed from the field observations.

4. Data Analysis

4.1. Adjustment of Sensors: The data set from the field study was divided into six segments in order to allow for easy manipulation of the data in the computer spreadsheets. The time period covered by each segment is listed in Table 1. The two regression equations derived from the wind tunnel test prior to installation were used to adjust the wind speeds collected at both heights. These adjustments were necessary to eliminate the differences between the two different types of wind sensors, thus making the values more comparable.

The regression equation, $Y = -1.719582 + 1.015452X$, was used to adjust the 3-metre Met One speeds and the resulting values are referred to as 'Spd3A' (3-metre speed adjusted). Similarly,

Y = .332905 +.996931X, was used to adjust the R.M. Young 10-metre speeds and these values are referred to as 'Spd10A' for 10-metre speeds adjusted. Figures 3.1-3.6 show these adjusted 3-metre wind speeds plotted against their corresponding 10-metre values. The summary of the 'fit' of the two linear regressions is shown in Table 2.

Table 1.
Time period covered by each segment of the data set.

Segment 1:	Julian	day	176	1800	UTC	to	Julian	day	186	1200 UTC
Segment 2:	"	"	186	1300	"	"	"	"	196	0800 "
Segment 3:	"	"	196	0900	"	"	"	"	206	0500 "
Segment 4:	"	"	206	0600	"	"	"	"	216	0100 "
Segment 5:	"	"	216	0200	"	"	"	"	225	2100 "
Segment 6:	"	"	225	2200	"	"	"	"	231	1600 "

Table 2.
Summary of the 'fit' of the two linear regressions used to adjust the data from the two wind speed sensors.

	Met One	R.M.Young
Estimated standard error of slope:	.00601	.004173
Estimated standard error of intercept:	.248601	.168303
Computed t value for slope:	168.960	238.927
Computed t value for intercept:	-6.917	1.978
Correlation coefficient:	.9999	.9999
R-squared:	0.9998	0.9999
Percent of variation explained by model:	99.98	99.99
Estimated standard error of estimate:	.355668	.25153

When a regression model is selected for an application, it cannot be certain that the model is appropriate. The model can be examined for its aptness by observing the scatter plots of the residual. A residual is the difference between the observed value and the fitted value. As the residuals fall within a horizontal band centred around zero (see Figure 4) and display no positive or negative tendencies, it can be concluded that the model is suitable.

Each 3-metre adjusted wind speed was then subtracted from the corresponding 10-metre adjusted speed and the resulting value is referred to as 'S10A-S3A'.

4.2. Estimation of the wind speeds at 10 metres: The World Meteorological Organization (1983) suggests that "where in open terrain the anemometer cannot be exposed at the standard height then the observed wind speeds can be adjusted to provide an estimate of the winds at ten metres above ground using a mean variation of wind speed with height based on a simplified form of Hellman's formula, namely

$$V_h = V_{10}[0.233 + 0.656\log_{10}(h + 4.75)]$$

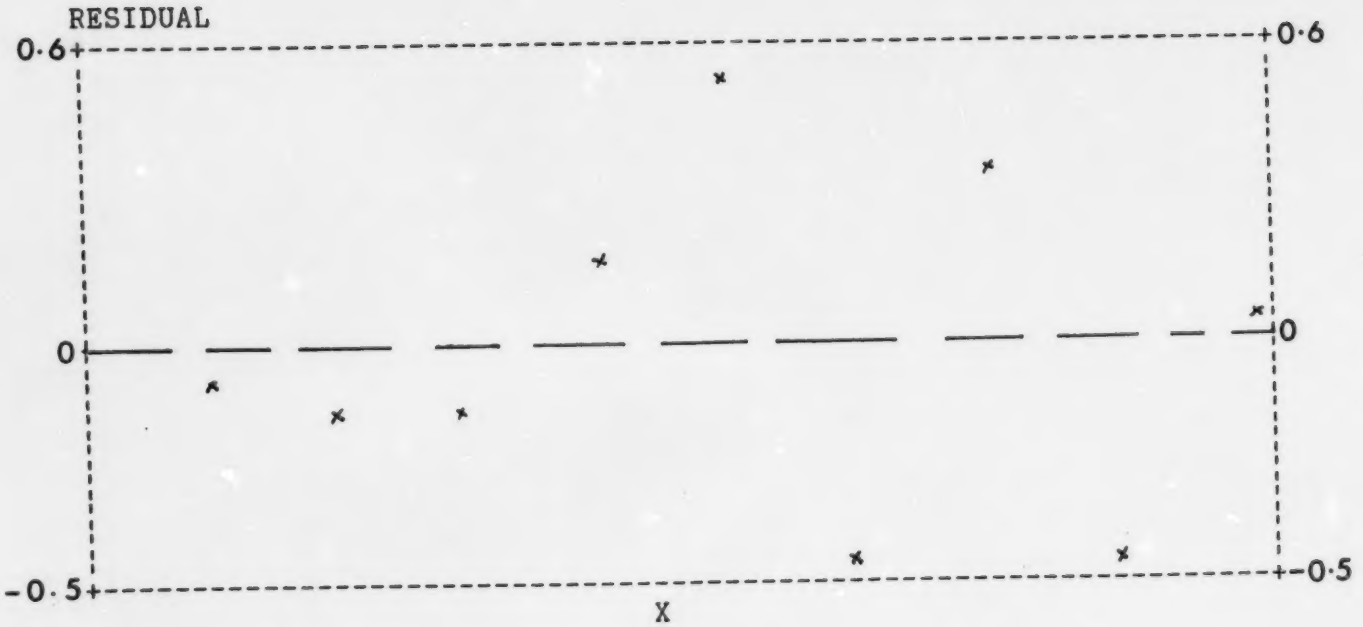

Figure 4: The scatter plots of the residual resulting from the regression of the Met One vs. the wind tunnel wind speeds.

where V_h is the wind at height h metres and V_{10} is the wind speed at ten metres above ground."

The simplified form of Hellman's formula was applied to the adjusted 3-metre speeds to further enhance the comparability of the two data sets. The resulting speeds, S3A*F, were compared with the 10-metre adjusted speeds using a correlation analysis.

The correlation coefficients ranged from a low of .778 to a high of .941. Table 3 shows the means, standard deviations, and correlation coefficients of the 10-metre adjusted speeds and the 3-metre adjusted speeds modified by a simplified form of Hellman's formula. Figures 5.1-5.6 show the comparison of the adjusted 10-metre speeds with the adjusted 3-metre speeds modified by a simplified form of Hellman's formula.

Table 3.

Means, standard deviations, and correlation coefficients of the 10-metre adjusted speeds and the 3-metre adjusted speeds modified by a simplified form of Hellman's formula.

Variable	Mean	St. Dev.	Sample Size
Seg.1-1s3a*f	20.0	11.2	236
Seg.1-1spd10A	19.9	10.3	236
Correlation Coefficient of the two variables: .84			
Seg.2-1s3a*f	24.6	13.4	237
Seg.2-1spd10A	26.2	13.8	237
Correlation Coefficient of the two variables: .78			
Seg.3-1s3a*f	16.2	10.4	237
Seg.3-1spd10A	15.6	9.8	237
Correlation Coefficient of the two variables: .90			
Seg.4-1s3a*f	13.6	8.2	237
Seg.4-1spd10A	12.6	8.4	237
Correlation Coefficient of the two variables: .85			
Seg.5-1s3a*f	13.6	8.7	237
Seg.5-1spd10A	13.8	8.4	237
Correlation Coefficient of the two variables: .88			
Seg.6-1s3a*f	13.8	11.9	140
Seg.6-1spd10A	13.7	11.2	140
Correlation Coefficient of the two variables: .94			

When the observations in which the 3-metre adjusted speeds were stronger than those at the 10-metre level were excluded from the analysis, much stronger correlations were calculated. A summary of these correlations are shown in Table 4. Averages, maxima, minima, and standard deviations were computed for each variable in each of the six segments

Table 4

Means, standard deviations, and correlation coefficients of the 10-metre adjusted speeds and the 3-metre adjusted speeds modified by a simplified form of Hellman's formula. An observation was excluded if the 3-metre speed was greater than the 10-metre speed.

Variable	Mean	Stand. Deviation	Sample Size
Seg.1-1s3a*f	19.9	11.0	179
Seg.1-1spd10A	20.1	10.9	179
Correlation Coefficient of the two variables: .95			
Seg.2-1s3a*f	25.6	13.9	204
Seg.2-1spd10A	25.2	12.6	204
Correlation Coefficient of the two variables: .97			
Seg.3-1s3a*f	16.3	10.9	165
Seg.3-1spd10A	16.8	10.2	165
Correlation Coefficient of the two variables: .97			
Seg.4-1s3a*f	13.7	8.6	185
Seg.4-1spd10A	13.5	8.2	185
Correlation Coefficient of the two variables: .94			
Seg.5-1s3a*f	14.0	9.1	189
Seg.5-1spd10A	14.4	8.0	189
Correlation Coefficient of the two variables: .96			
Seg.6-1s3a*f	14.0	12.6	109
Seg.6-1spd10A	15.0	11.9	109
correlation Coefficient of the two variables: .96			

4.3 Statistical Test: Two sensors can produce the same average readings even if those readings are different for individual observations. The difference, d = S3F - S10A is calculated; d is assumed to be a random variable normally distributed with mean μ_d and an unknown variance σ_d^2. The following test can be used to verify that the sensors can produce the same average readings:

$$\text{Test: } H_o = \mu_d = 0 \quad \text{vs.} \quad H_o = \mu_d \neq 0$$
$$\text{Reject } H_o \text{ if } |t| \geq t_{n-1}(\alpha/2)$$
$$\text{where } t = (d - \mu_d)/s_d$$

$$d = \left(\sum_{i=1}^{n} d_i\right)/n \ , \ s_d = \sqrt{\left(\sum_{i=1}^{n} (d_i - d)^2/(n-1)\right)}$$

By selecting $\alpha = 0.05$ and since n>90, then $t_{n-1}(\alpha/2) = 1.98$. Table 5 shows the action which can be taken when this statistical test is used and Figures 6.1-6.6 show the normal goodness of fit test for each of the six segments of the data set. The reader is referred to Neter et al. (1985) and Baillargeon and Rainville (1977) for further reading on this test.

Table 5.
Results of the statistical test.

Variable	μ_d	s_d	t	Action
Segment 1	1.29	4.28	0.30	Keep H_o
Segment 2	1.08	3.40	0.32	keep H_o
Segment 3	0.99	3.51	0.28	keep H_o
Segment 4	0.54	3.03	0.18	keep H_o
Segment 5	0.41	2.98	0.14	keep H_o
Segment 6	0.14	4.04	0.003	keep H_o

From the above table of the results of the statistical test and also from the normal-goodness-of-fit test of Figure 5, it can be concluded that both sensors provide the same average results.

5. Discussion

In theory, wind speed increases as the effect of friction decreases; as the observational distance above ground increases, the friction resulting from rough terrain decreases and therefore the wind speed increases. This theory holds true only if there are no other mechanisms such as thermal heating and cooling or down drafts operating.

The initial analysis indicated that wind speeds at 10 metres were not always greater than those at 3 metres as was expected. The differences between the adjusted 10-metre and 3-metre speeds, S10A-S3A, showed that some speeds were greater at 3 metres than at 10 metres. As windy and mainly cool conditions prevailed over the entire period of the comparison (maximum temperature was 14.8°C), thermal heating and cooling are not considered to be influencing factors.

When the negative differences were isolated and their wind directions examined, it was found that with rapidly changing wind direction, the speeds at 3 metres were stronger than those at 10 metres. As the vane of the 10-metre R.M. Young Wind Monitor was changing direction, the propeller was not facing the prevailing wind and the speed was therefore underestimated. This problem, associated with the dynamic response of the sensor, exists with most propeller-type anemometers, but it is non-existent with the independent cup and vane system. Many examples of these negative differences with rapidly changing direction can be seen in Figures 7.1-7.6.

Further examination of the two data sets showed that with winds from the west sector, some speeds were greater at 3 metres than at 10 metres. Three of the more significant occurrences are documented below:

Case 1: Julian day 183, hour 1500 UTC: The 26 km/h 3-metre adjusted wind speed was 11 km/h stronger than the 10-metre adjusted speed; the wind directions were 249° at 3 metres and 275° at 10 metres; the temperature was 2.7°C.

Case 2: Julian day 220, hour 0200 UTC: The 19 km/h 3-metre adjusted wind speed was 9 km/h stronger than the 10-metre adjusted speed; the wind directions were 311° at 3 metres and 312° at 10 metres; the temperature was 5.9°C.

Case 3: Julian day 231, hour 0600 UTC: The 32 km/h 3-metre adjusted wind speed was 12 km/h stronger than the 10-metre adjusted speed; the wind directions were 325° at 3 metres and 293° at 10 metres; the temperature was 1.7°C.

In these cases, the wind speeds were relatively strong, the wind direction was constant and the temperatures were not warm enough to cause thermal heating. These therefore rule out any instrument characteristic such as the effect of a rapidly changing direction or the effects of up-drafts and down-drafts associated with unequal heating and cooling. Turbulence, caused by the topographical feature to the west of the site, appears to be responsible for these negative wind profile.

When the observed 10-metre adjusted speeds were subtracted from the adjusted and modified 3-metre speeds, it was found that in a few cases extreme maxima and minima occurred. It is interesting to note that these extreme differences also occurred with winds from the western sector and the winds at both levels appear to be affected by the topographical feature to the east of the site. A few of the greatest differences are shown in Table 6.

Table 6.
A few extreme maxima and minima resulting from S3F-S10A and their corresponding wind data.

Day	Hour	S3F-S10A	DIR3	SPD3A	S3A*F	DIR10	SPD10A
183	1500	17.0	249	26	32.3	275	15
177	700	-14.4	332	17	20.8	331	35
187	2100	10.9	203	49	59.7	201	49
189	00	-10.7	240	5	6.7	183	17
200	700	-12.2	211	21	25.4	200	38
208	2100	11.1	186	26	32.4	185	21
220	200	13.6	312	19	22.8	312	9
230	1500	-20.0	356	8	9.3	324	29
231	600	19.1	325	32	38.9	293	20

Although much stronger correlation coefficients occurred when the observations in which the 3-metre adjusted speeds were stronger than those at 10-metres were excluded from the analysis, the correlations which included all the observations were also satisfactory.

Further analysis of these negative differences is beyond the scope of this project; however, the reader is encouraged to read Salmon et al. (1988a), Salmon et al. (1988b), and Walmsley et al. (1989) in which the subject of topographical effects on wind speeds is documented.

6. Conclusion

It is difficult to adjust the wind speeds observed at the 3-metre level to provide an accurate standard 10-metre level value without having a good knowledge of the site description. Even with this knowledge, sometimes it is difficult to determine which forces are reflected in the data.

At Hot Weather Creek, topography appears to play an important role on the winds from the west sector, sometimes causing the 3-metre speeds to be stronger than those at 10 metres while at other times the reverse is the case. Satisfactory correlation coefficients occurred between the two data sets after the speeds were adjusted and those recorded at 3 metres were modified; however, with the exclusion of the speeds which were stronger at 3 metres than at 10 metres much stronger correlations resulted. The simplified form of the Hellman's formula as recommended by WMO proved to be a good method of estimating the 10-metre speeds from those taken at 3 metres. Its use is recommended.

Instrument characteristics were responsible for some of the erroneous data which occurred. As was stated earlier, comparisons of this type should be done with similar sensors but if this is impossible, then any peculiarities of the sensors should be known and they should be given careful consideration during the analysis of the data. In the case of the R.M. Young Wind Monitor at Hot Weather Creek, it became apparent that during periods of rapidly changing direction, the wind speed was underestimated.

The results of this study show that it is possible to adjust the wind speeds recorded at 3 metres to provide an estimate of the wind at 10 metres using a mean variation of wind speed with height based on a simplified form of Hellman's formula. This technique will be used to adjust future 3-metre wind speeds recorded at Hot Weather Creek for comparison with the Eureka 10-metre data.

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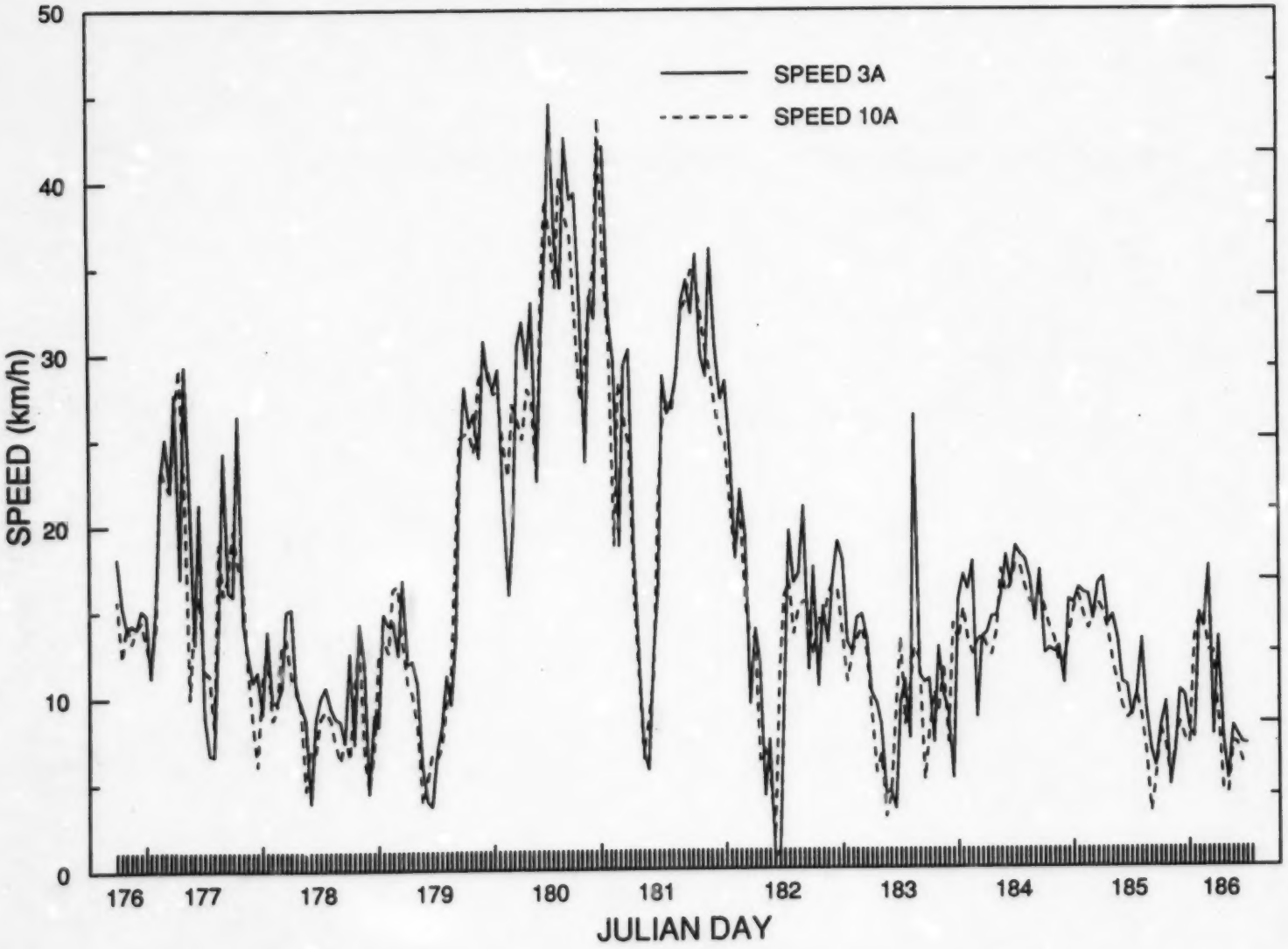


Figure 3.1: Adjusted 3-metre wind speeds plotted against their corresponding 10-metre values (days 176-186).

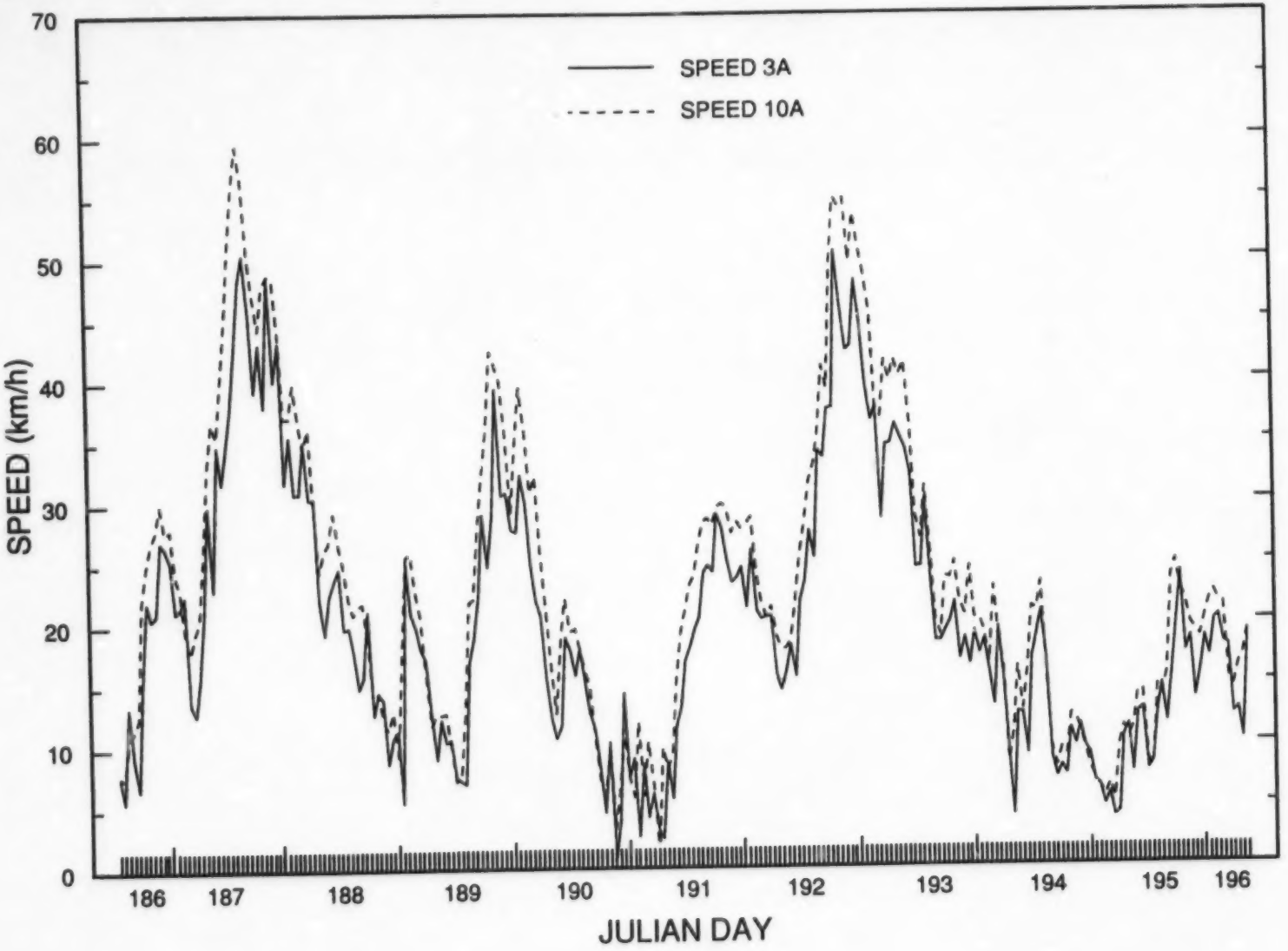


Figure 3.2: Adjusted 3-metre wind speeds plotted against their corresponding 10-metre values (days 186-196).

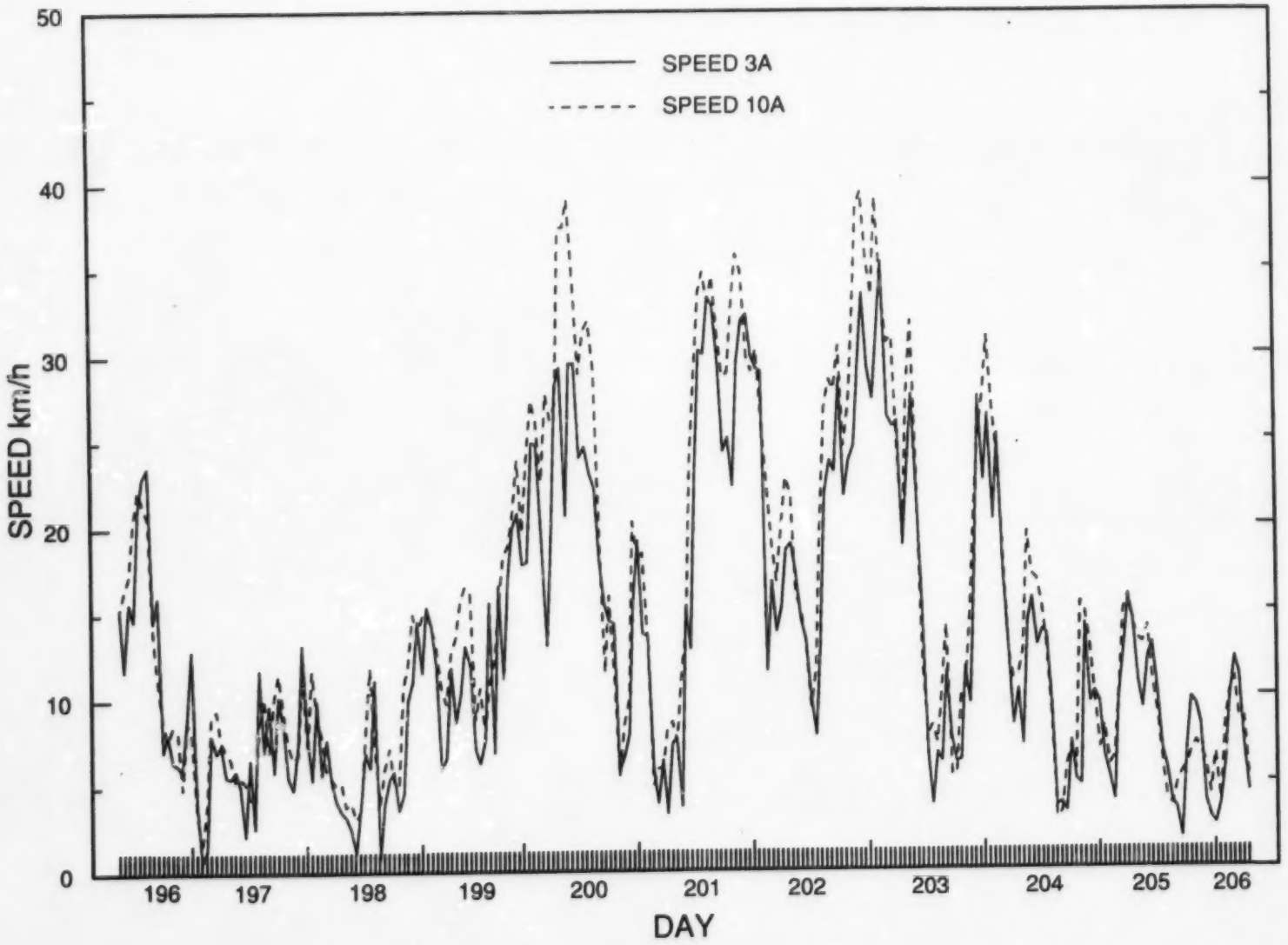


Figure 3.3: Adjusted 3-metre wind speeds plotted against their corresponding 10-metre values (days 196-206).

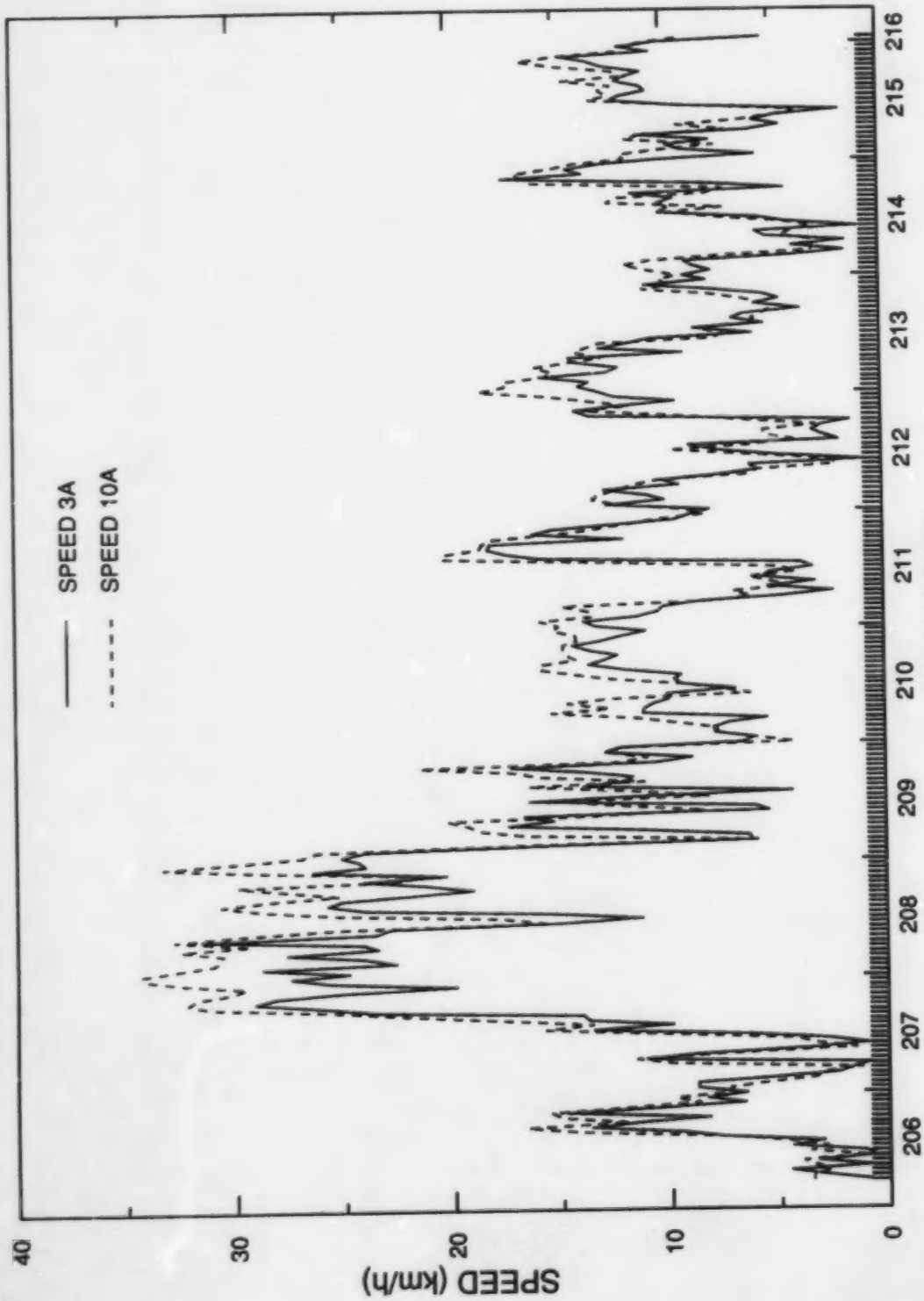


Figure 3.4: Adjusted 3-metre wind speeds plotted against their corresponding 10-metre values (days 206-216).

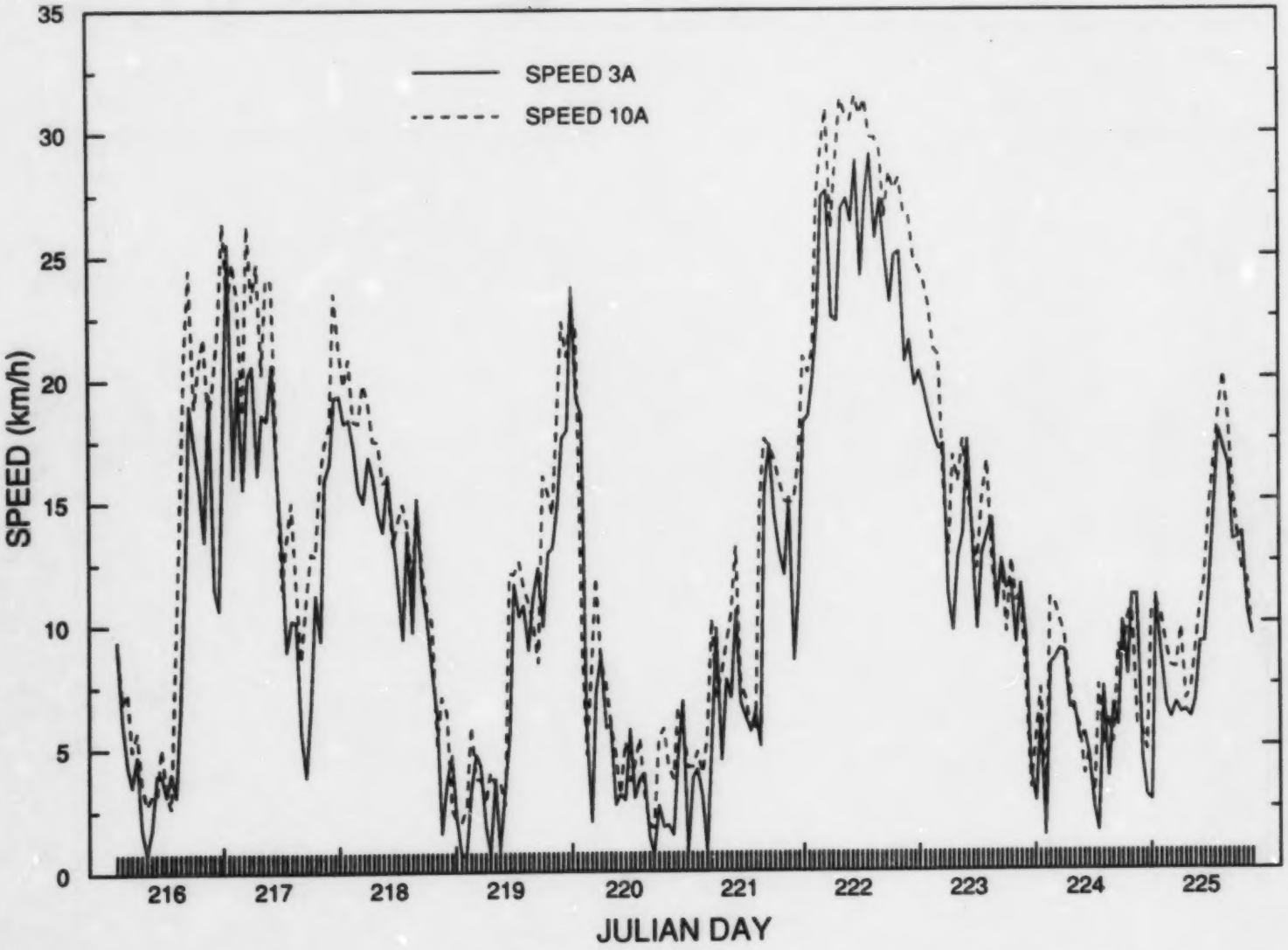


Figure 3.5: Adjusted 3-metre wind speeds plotted against their corresponding 10-metre values (days 216-225).

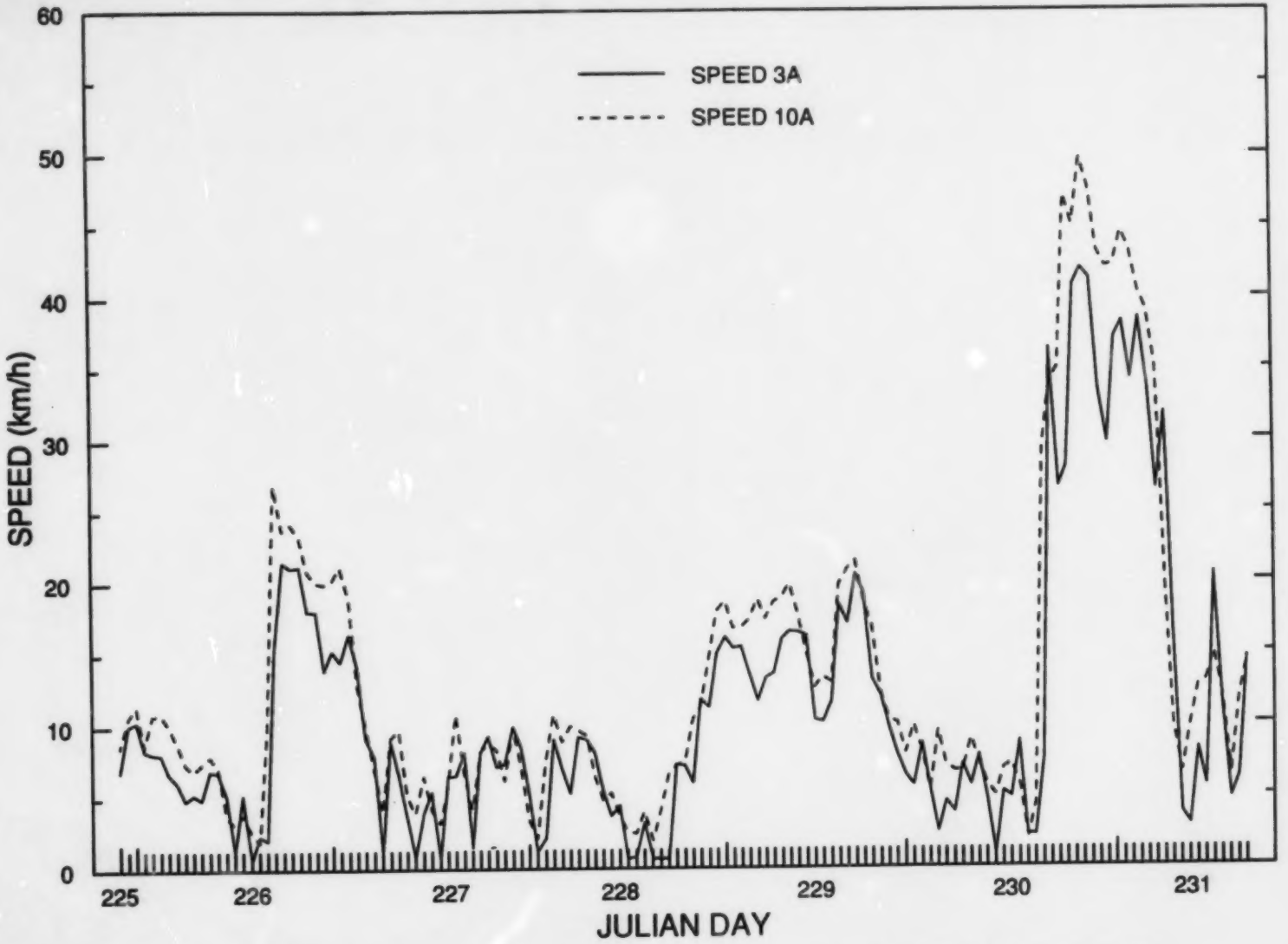


Figure 3.6: Adjusted 3-metre wind speeds plotted against their corresponding 10-metre values (days 225-231).

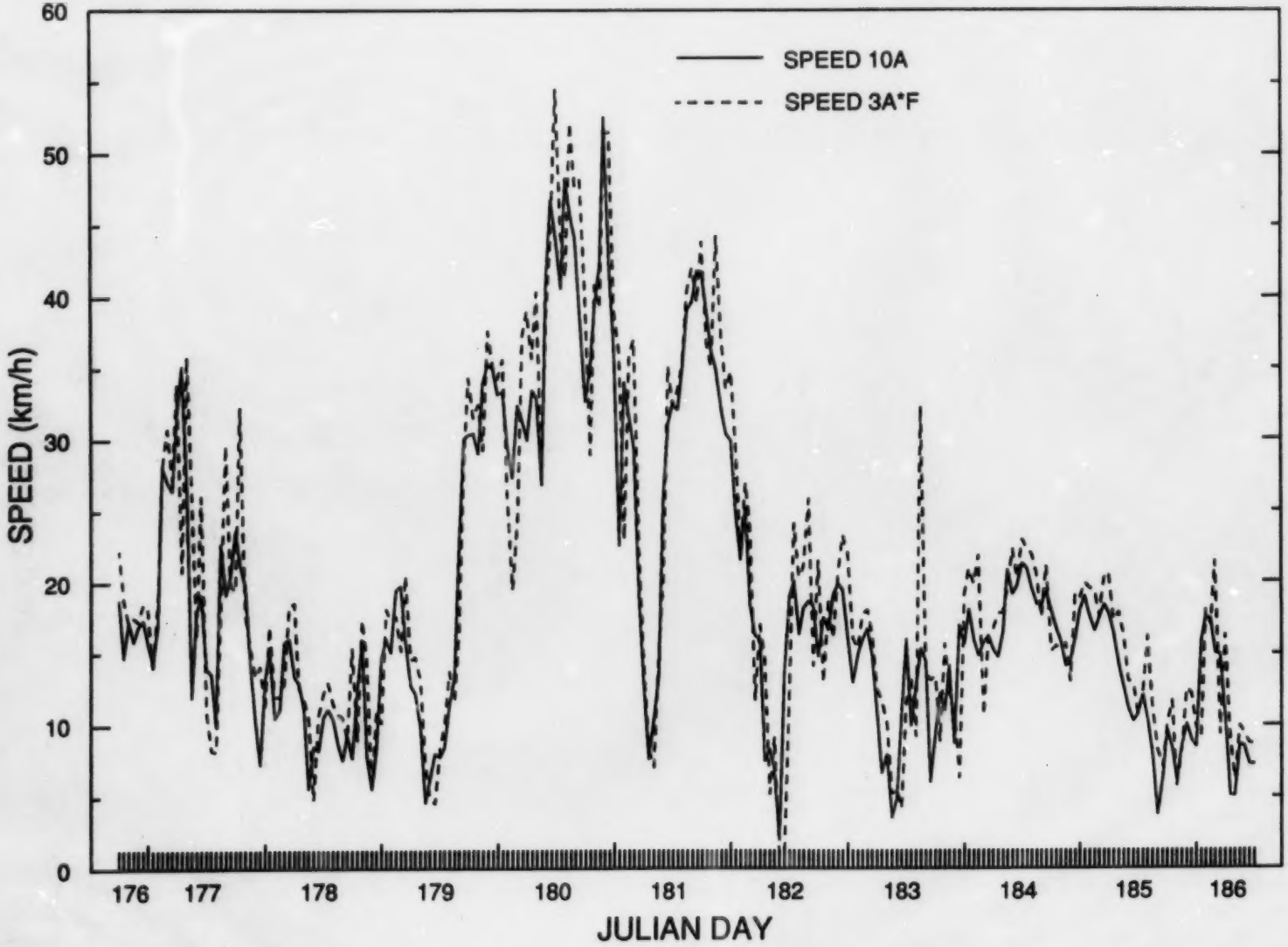


Figure 5.1: Comparison of the adjusted 10-metre speeds with the 3-metre speeds modified by a simplified form of Hellman's formula (days 176-186).

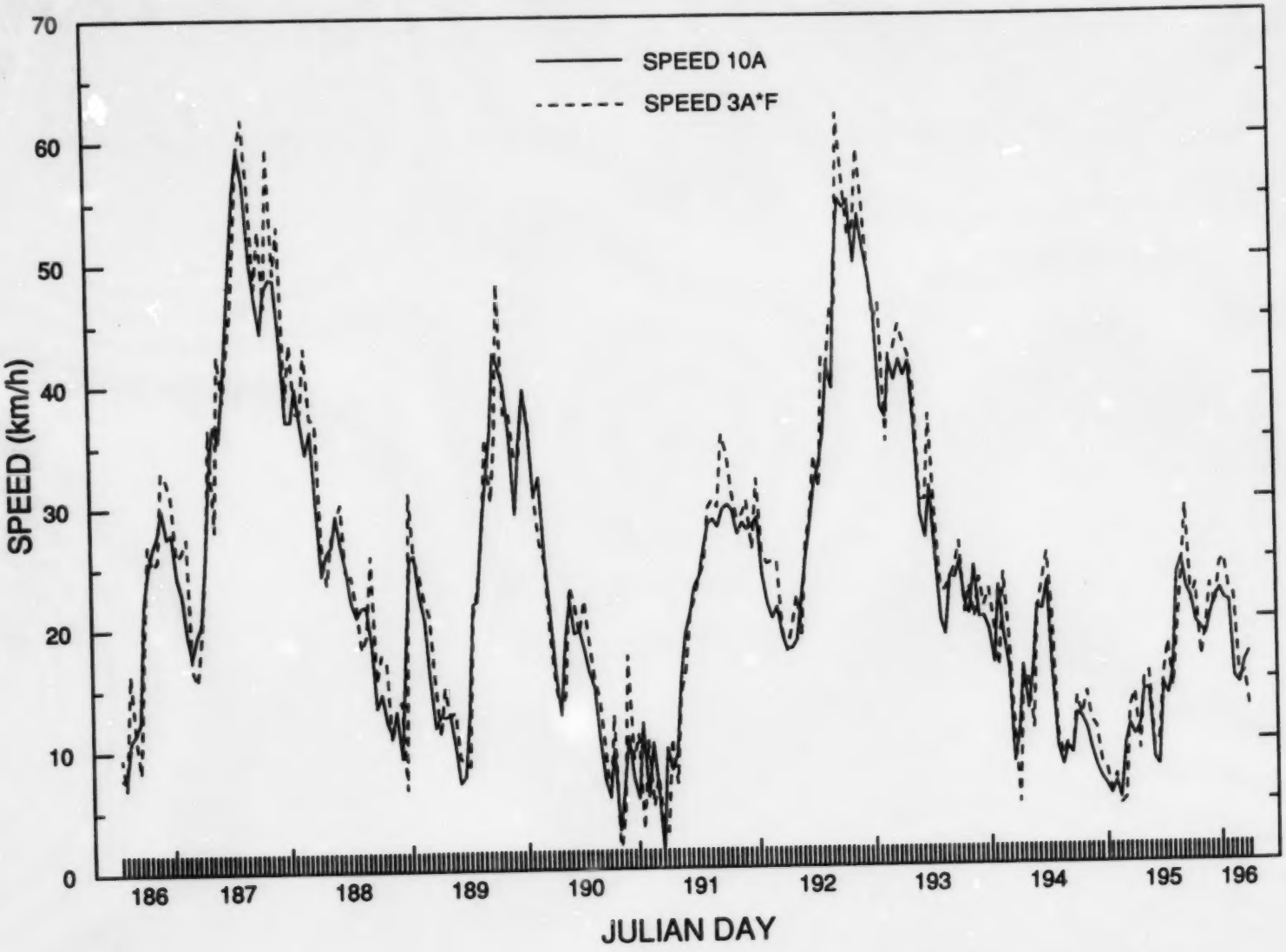


Figure 5.2: Comparison of the adjusted 10-metre speeds with the 3-metre speeds modified by a simplified form of Hellman's formula (days 186-196).

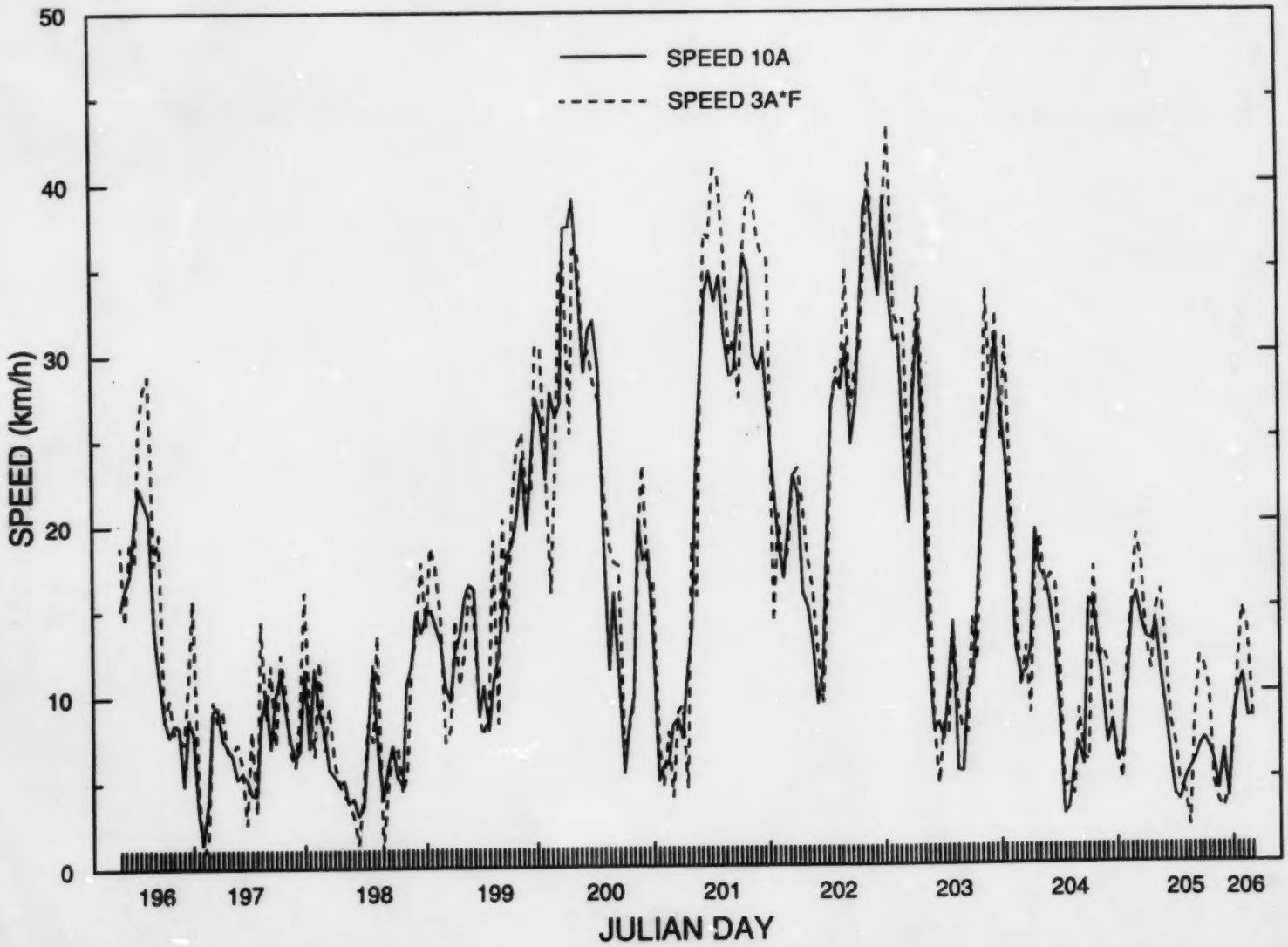


Figure 5.3: Comparison of the adjusted 10-metre speeds with the 3-metre speeds modified by a simplified form of Hellman's formula (days 196-206).

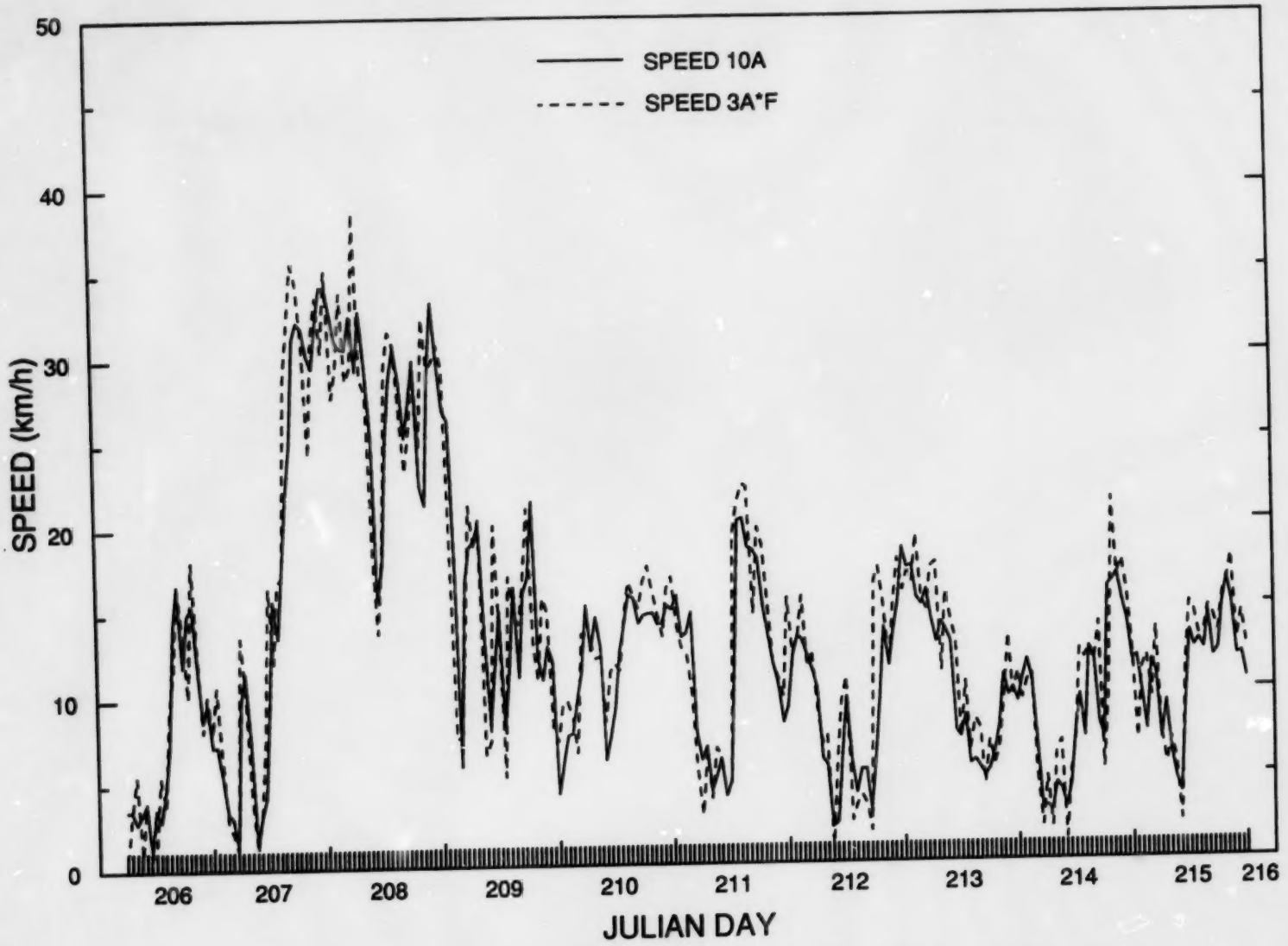


Figure 5.4: Comparison of the adjusted 10-metre speeds with the 3-metre speeds modified by a simplified form of Hellman's formula (days 206-216).

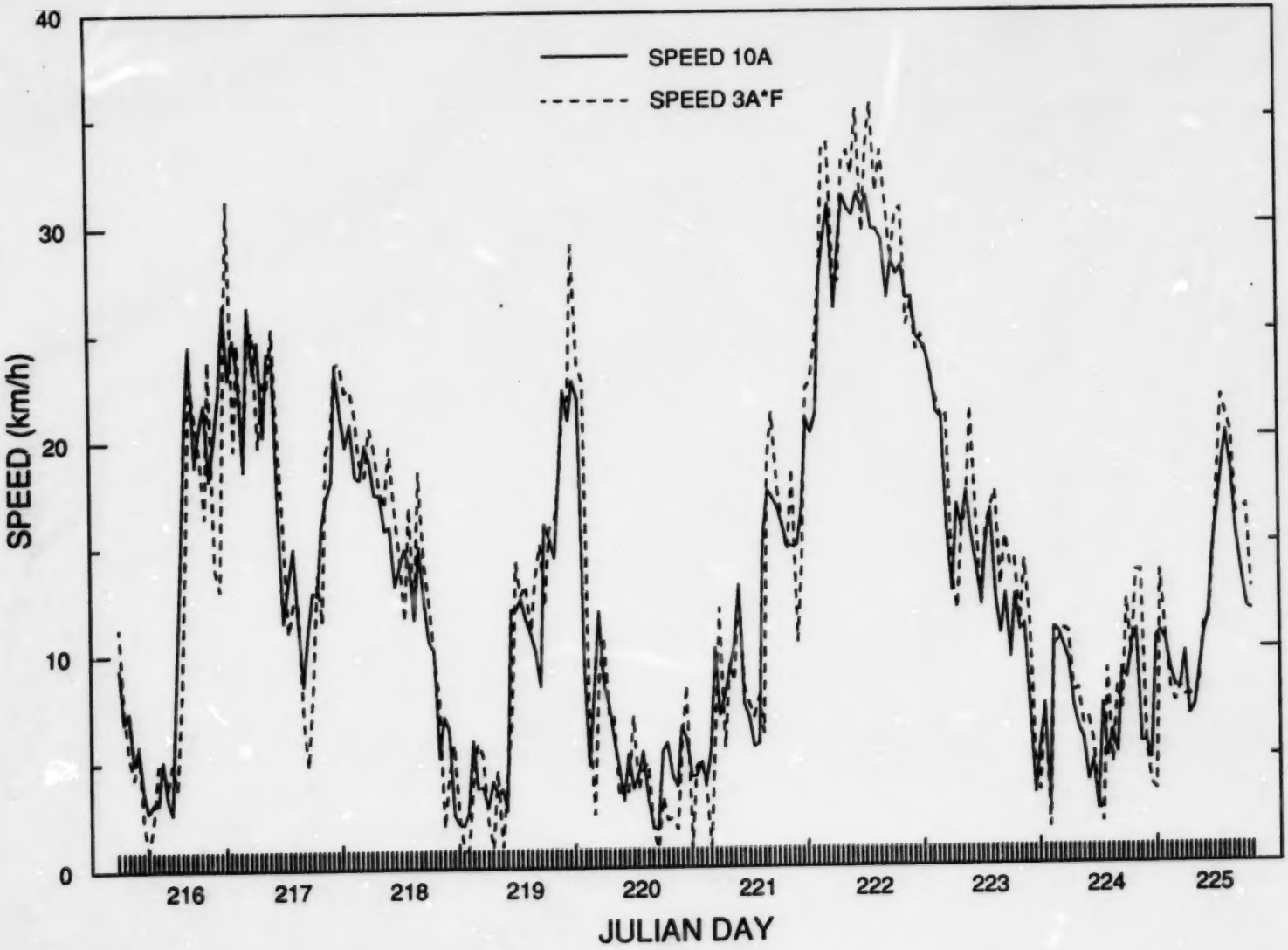


Figure 5.5: Comparison of the adjusted 10-metre speeds with the 3-metre speeds modified by a simplified form of Hellman's formula (days 216-225).

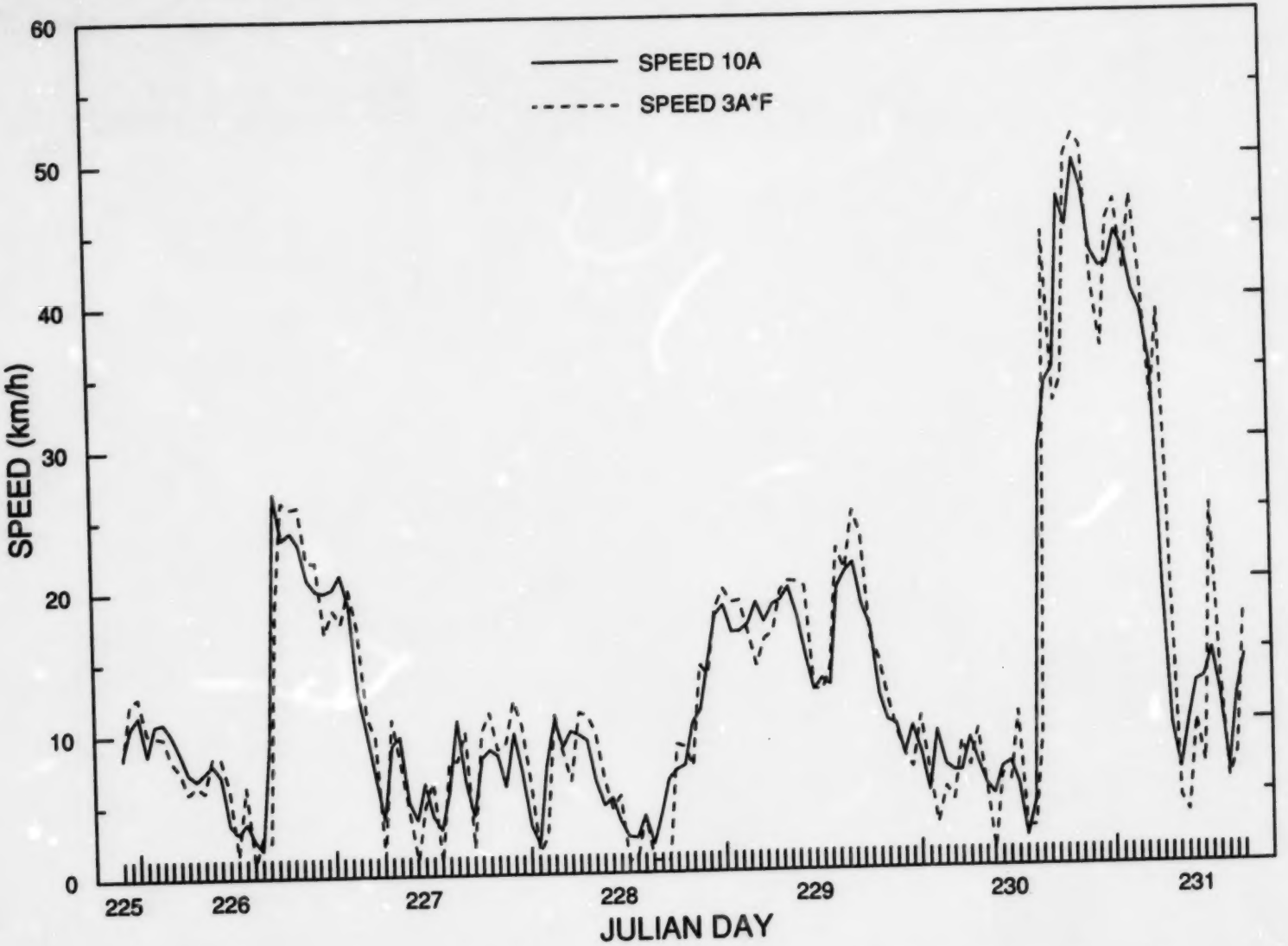


Figure 5.6: Comparison of the adjusted 10-metre speeds with the 3-metre speeds modified by a simplified form of Hellman's formula (days 225-231).

Figure 6.1: Normal goodness fit test for d = S3F - S10A (days 176-186).

```
.... OPTION 1: NORMAL GOODNESS OF FIT TEST ....

 f(o)    f(e)     Z Scale and Histogram
------  ------   +-------------------------
   2      0.3     ¦ **
                -3+
   4      5.1     ¦ ****
                -2+
  29     32.1     ¦ ******************************
                -1+
  70     80.6     ¦ ********************** 70 ***************
                 0+
 102     80.6     ¦ ********************** 102 ***************
                 1+
  22     32.1     ¦ ************************
                 2+
   5      5.1     ¦ *****
                 3+
   2      0.3     ¦ **
```

Standardized Z-value	f(o)	f(e)	f(o)-f(e)	$[f(o)-f(e)]^2/f(e)$
Under -2.0	6	5.4	0.6	0.074
-2.0 to -1.0	29	32.1	-3.1	0.295
-1.0 to 0.0	70	80.6	-10.6	1.383
0.0 to 1.0	102	80.6	21.4	5.708
1.0 to 2.0	22	32.1	-10.1	3.165
2.0 and over	7	5.4	1.6	0.495
Total:	236	236.0	0.0	11.120

Chi-Square = 11.120 with d.f.= 3

Note: Details may not add to totals, due to rounding.
In the test, the first 2 and last 2 classes were combined to enlarge f(e).

Figure 6.2: Normal goodness fit test for d = S3F - S10A (days 186-196).

```
.... OPTION 1: NORMAL GOODNESS OF FIT TEST ....

 f(o)    f(e)     Z Scale and Histogram
------  ------   +-------------------------
   1      0.3     ¦ *
                -3+
   6      5.1     ¦ ******
                -2+
  25     32.2     ¦ **************************
                -1+
  85     80.9     ¦ ********************** 85 ***************
                 0+
  86     80.9     ¦ ********************** 86 ***************
                 1+
  28     32.2     ¦ ****************************
                 2+
   6      5.1     ¦ ******
                 3+
   0      0.3     ¦
```

Standardized Z-value	f(o)	f(e)	f(o)-f(e)	$[f(o)-f(e)]^2/f(e)$
Under -2.0	7	5.4	1.6	0.480
-2.0 to -1.0	25	32.2	-7.2	1.614
-1.0 to 0.0	85	80.9	4.1	0.208
0.0 to 1.0	86	80.9	5.1	0.322
1.0 to 2.0	28	32.2	-4.2	0.550
2.0 and over	6	5.4	0.6	0.069
Total:	237	237.0	0.0	3.243

Chi-Square = 3.243 with d.f.= 3

Note: Details may not add to totals, due to rounding.
In the test, the first 2 and last 2 classes were combined to enlarge f(e).

Figure 6.3: Normal goodness fit test for d = S3F - S10A (days 196-206).

```
.... OPTION 1: NORMAL GOODNESS OF FIT TEST ....

 f(o)    f(e)     Z Scale and Histogram
------  ------   +-------------------------
   3      0.3     ¦ ***
                -3+
   3      5.1     ¦ ***
                -2+
  25     32.2     ¦ **************************
                -1+
  90     80.9     ¦ ********************** 90 ***************
                 0+
  83     80.9     ¦ ********************** 83 ***************
                 1+
  26     32.2     ¦ **************************
                 2+
   7      5.1     ¦ *******
                 3+
   0      0.3     ¦
```

Standardized Z-value	f(o)	f(e)	f(o)-f(e)	$[f(o)-f(e)]^2/f(e)$
Under -2.0	6	5.4	0.6	0.069
-2.0 to -1.0	25	32.2	-7.2	1.614
-1.0 to 0.0	90	80.9	9.1	1.024
0.0 to 1.0	83	80.9	2.1	0.055
1.0 to 2.0	26	32.2	-6.2	1.198
2.0 and over	7	5.4	1.6	0.480
Total:	237	237.0	0.0	4.439

Chi-Square = 4.439 with d.f.= 3

Note: Details may not add to totals, due to rounding.
In the test, the first 2 and last 2 classes were combined to enlarge f(e).

Figure 6.4: Normal goodness fit test for d = S3F - S10A (days 206-216).

.... OPTION 1: NORMAL GOODNESS OF FIT TEST ....

f(o)	f(e)	Z Scale and Histogram
2	0.3	**
		-3+
5	5.1	*****
		-2+
22	32.2	**********
		-1+
91	80.9	********** 91 **********
		0+
90	80.9	********** 90 **********
		1+
18	32.2	**********
		2+
7	5.1	*******
		3+
2	0.3	**

Standardized Z-value	f(o)	f(e)	f(o)-f(e)	$[f(o)-f(e)]^2/f(e)$
Under -2.0	7	5.4	1.6	0.480
-2.0 to -1.0	22	32.2	-10.2	3.237
-1.0 to 0.0	91	80.9	10.1	1.262
0.0 to 1.0	90	80.9	9.1	1.024
1.0 to 2.0	18	32.2	-14.2	6.269
2.0 and over	9	5.4	3.6	2.415
Total:	237	237.0	0.0	14.686

Chi-Square = 14.686 with d.f.= 3

Note: Details may not add to totals, due to rounding.
In the test, the first 2 and last 2 classes were combined to enlarge f(e).

Figure 6.5: Normal goodness fit test for d = S3F - S10A (days 216-225).

```
.... OPTION 1: NORMAL GOODNESS OF FIT TEST ....

 f(o)    f(e)     Z Scale and Histogram
------  ------   +-------------------------
   2      0.3     ¦ **
                -3+
   6      5.1     ¦ ******
                -2+
  21     32.2     ¦ **********************
                -1+
  86     80.9     ¦ ********************** 86 ***************
                 0+
  94     80.9     ¦ ********************** 94 ***************
                 1+
  24     32.2     ¦ ************************
                 2+
   3      5.1     ¦ ***
                 3+
   1      0.3     ¦ *
```

Standardized Z-value	f(o)	f(e)	f(o)-f(e)	$[f(o)-f(e)]^2/f(e)$
Under -2.0	8	5.4	2.6	1.262
-2.0 to -1.0	21	32.2	-11.2	3.902
-1.0 to 0.0	86	80.9	5.1	0.322
0.0 to 1.0	94	80.9	13.1	2.122
1.0 to 2.0	24	32.2	-8.2	2.093
2.0 and over	4	5.4	-1.4	0.359
Total:	237	237.0	0.0	10.060

Chi-Square = 10.060 with d.f.= 3

Note: Details may not add to totals, due to rounding.
In the test, the first 2 and last 2 classes were combined to enlarge f(e).

Figure 6.6: Normal goodness fit test for d = S3F - S10A (days 225-231).

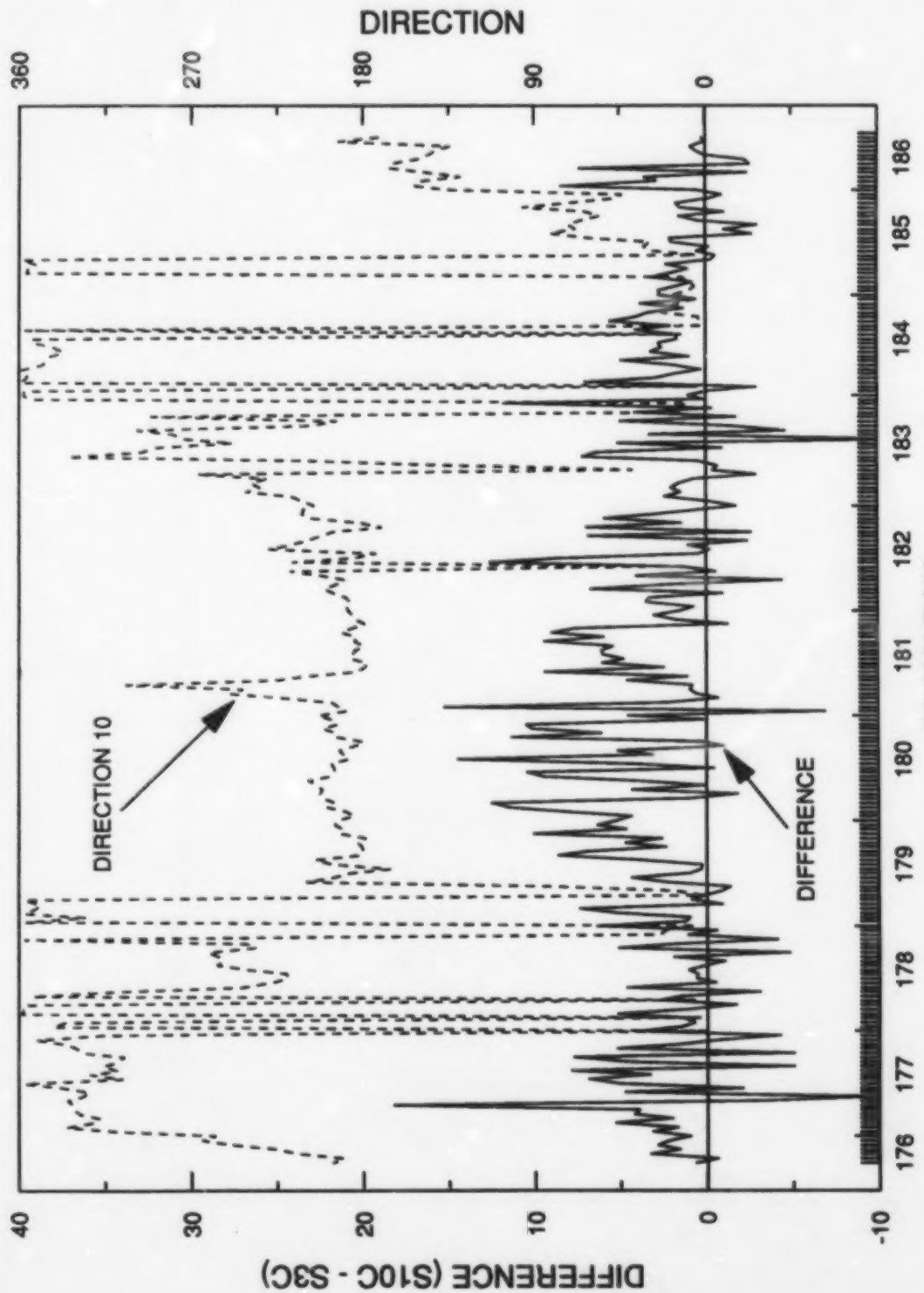
```
.... OPTION 1: NORMAL GOODNESS OF FIT TEST ....

 f(o)    f(e)     Z Scale and Histogram
------  ------   +-------------------------
   2      0.2     ¦ **
                -3+
   1      3.0     ¦ *
                -2+
  10     19.0     ¦ **********
                -1+
  57     47.8     ¦ ********************** 57 ***************
                 0+
  60     47.8     ¦ ********************** 60 ***************
                 1+
   6     19.0     ¦ ******
                 2+
   3      3.0     ¦ ***
                 3+
   1      0.2     ¦ *
```

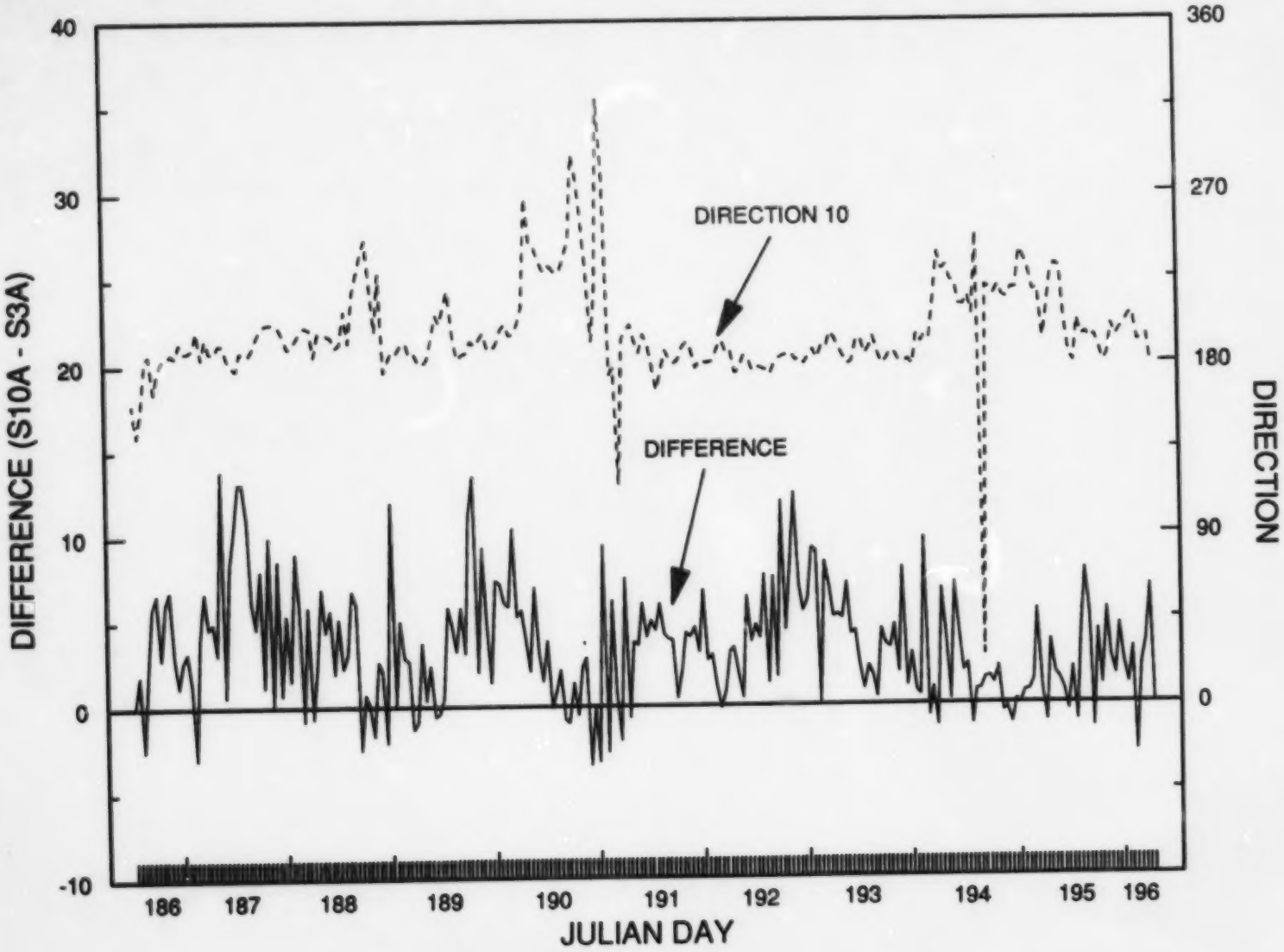
Standardized Z-value	f(o)	f(e)	f(o)-f(e)	$[f(o)-f(e)]^2/f(e)$
Under -2.0	3	3.2	-0.2	0.011
-2.0 to -1.0	10	19.0	-9.0	4.283
-1.0 to 0.0	57	47.8	9.2	1.776
0.0 to 1.0	60	47.8	12.2	3.121
1.0 to 2.0	6	19.0	-13.0	8.919
2.0 and over	4	3.2	0.8	0.209
Total:	140	140.0	0.0	18.319

Chi-Square = 18.319 with d.f.= 3

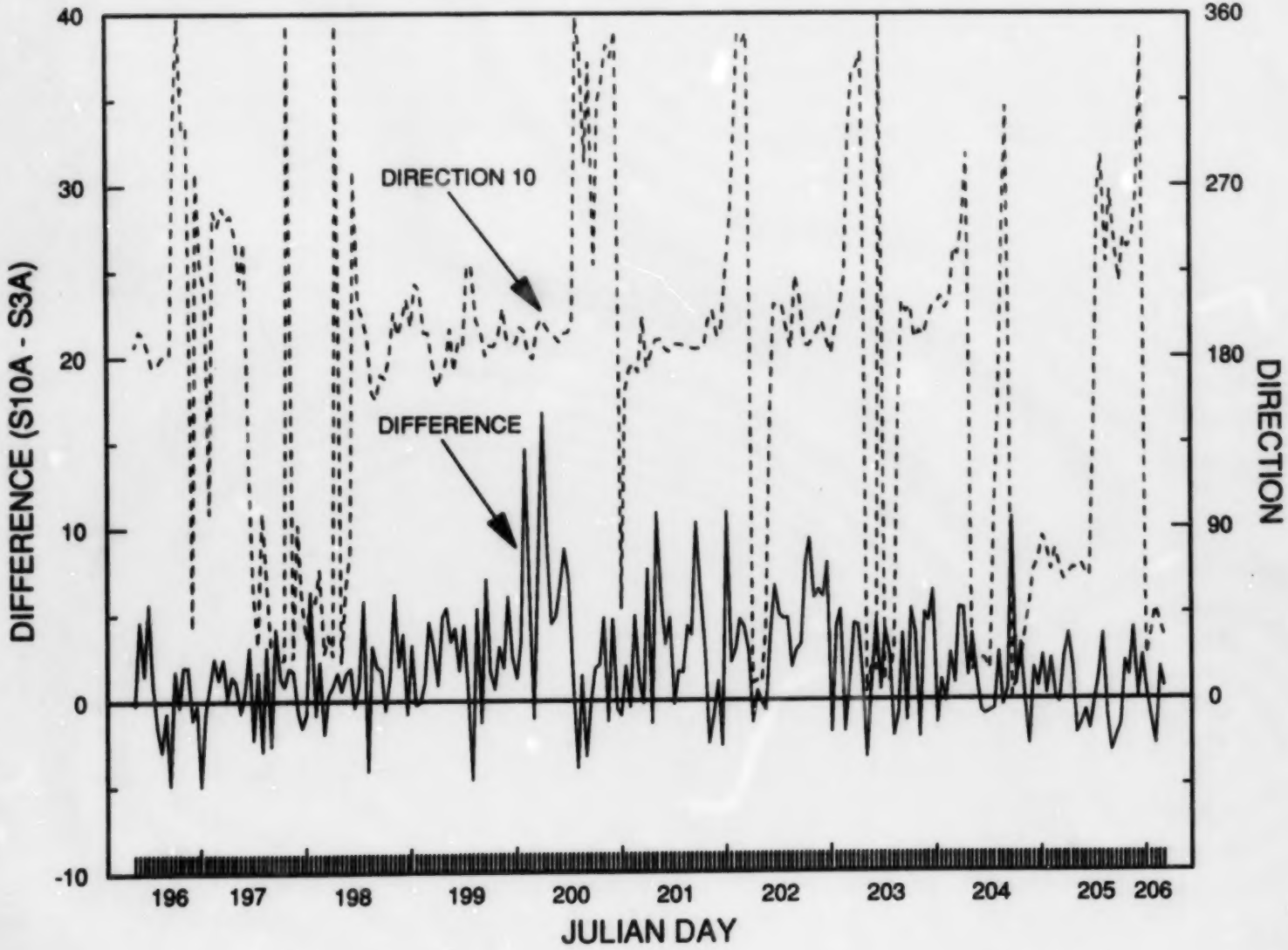
Note: Details may not add to totals, due to rounding.
In the test, the first 2 and last 2 classes were combined to enlarge f(e).



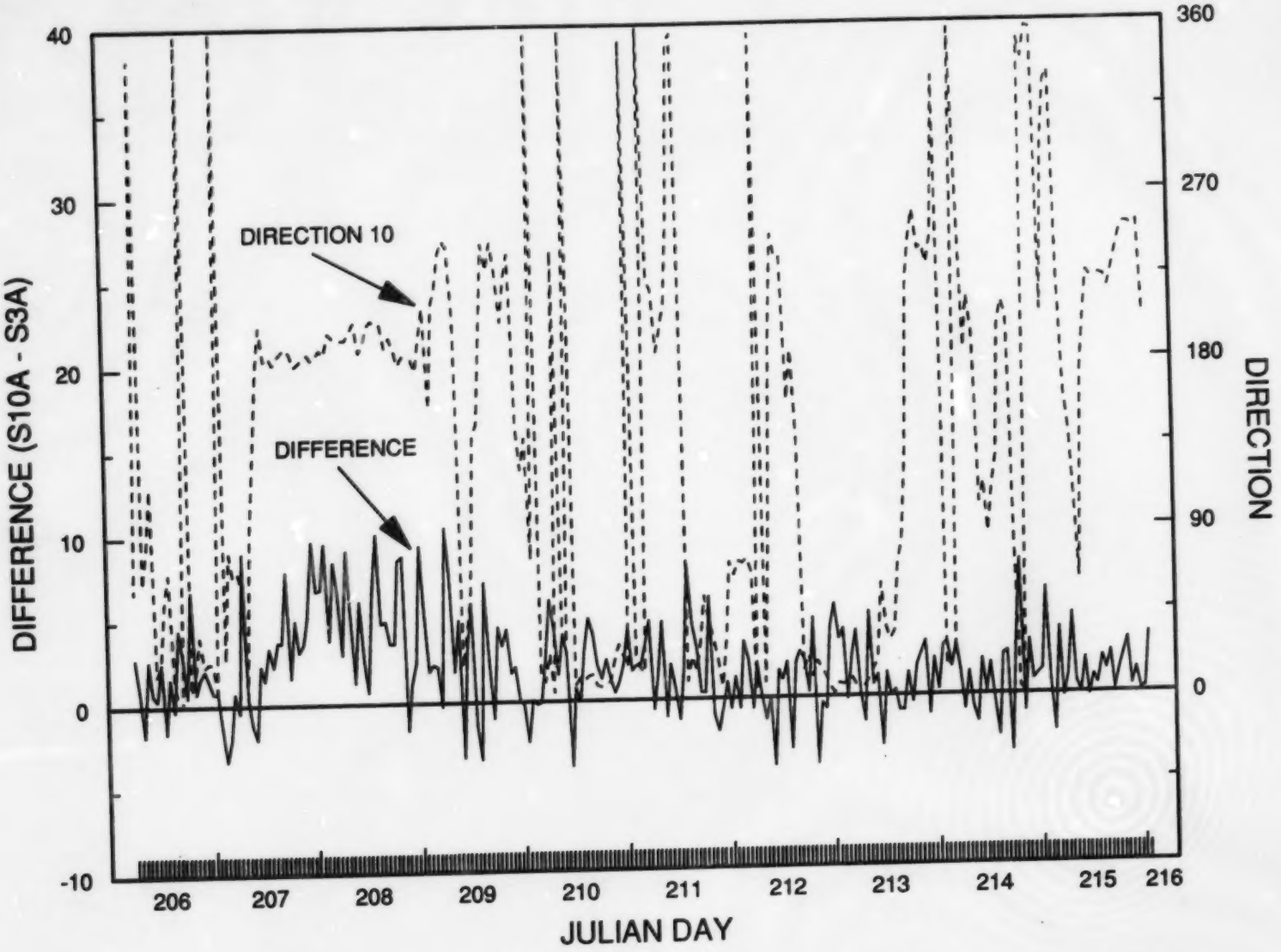
Figures 7.1: Differences between the adjusted wind speeds at both levels plotted against the direction at 10 metres (days 176-186).



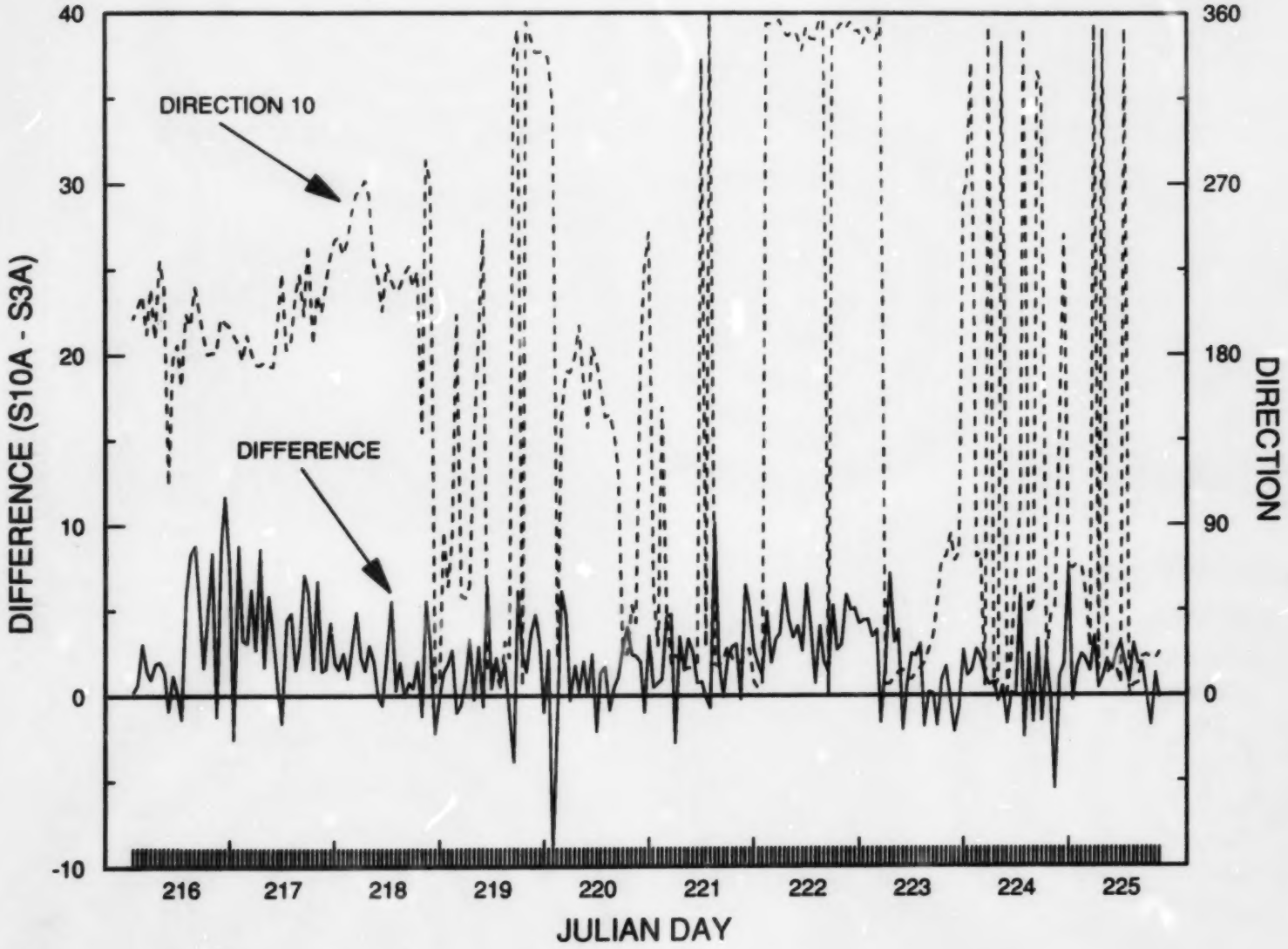
Figures 7.2: Differences between the adjusted wind speeds at both levels plotted against the direction at 10 metres (days 186-196).



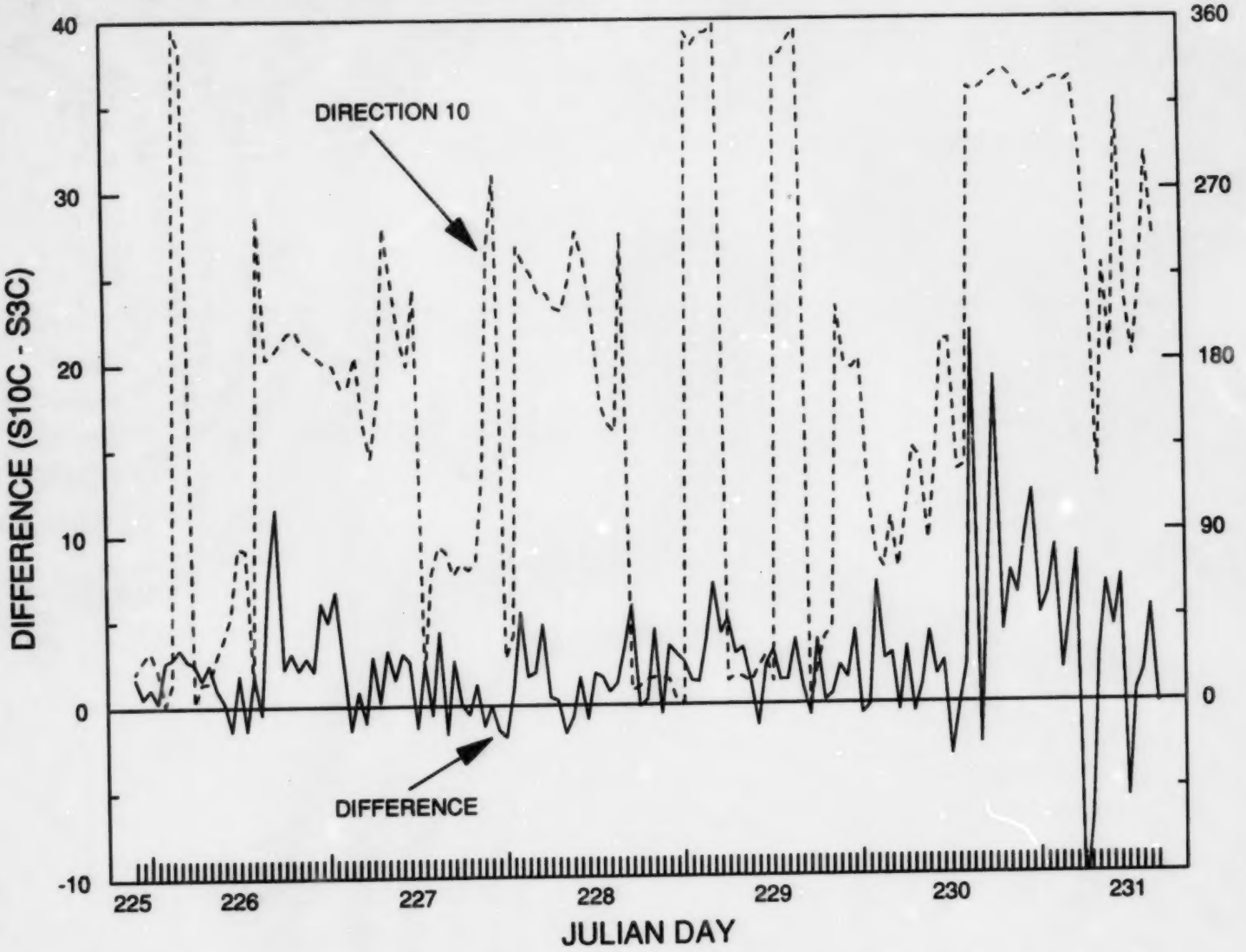
Figures 7.3: Differences between the adjusted wind speeds at both levels plotted against the direction at 10 metres (days 196-206).



Figures 7.4: Differences between the adjusted wind speeds at both levels plotted against the direction at 10 metres (days 206-216).



Figures 7.5: Differences between the adjusted wind speeds at both levels plotted against the direction at 10 metres (days 216-225).



Figures 7.6: Differences between the adjusted wind speeds at both levels plotted against the direction at 10 metres (days 225-231).